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Project SUTOR

Superconducting Speed-Controlled Torque Motor for 25.000Nm

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Abstract

SUTOR is a project that is supported by the german ministry of economy and technology (FKZ 0327866A). The partners working on this project are Oswald Elektromotoren and Hochschule Aschaffenburg. Oswald is responsible for the layout of the Motor and its cryostat. Together with the Hochschule Aschaffenburg, Oswald has build a number of coils to determine the loss rates of superconductors when used with AC current and in external, oscillating magnetic fields. These results are taken to proof the at Oswald developed calculations for superconducting motors. The Hochschule Aschaffenburg is measuring the loss rates in superconducting coils and builds an inverter to fit the special requests a motor has when running with superconducting wires.
The aim of this project is to realize a high torque motor that has compared to conventional torque motors a lower volume and weight, a higher efficiency and an increased dynamic acceleration.

1. Introduction

The general production program of Oswald consists of electric motors up to more than 1000 kW output power, so-called torque motors up to 600 kNm torque, linear motors up to 100 kN force and water-cooled and superconducting magnet systems. Since many years we develop and construct superconducting motors. Our program includes rotating superconducting synchronous motors up to several hundred kW and linear motors up to 45 kN axial force. Presently we focus our activities on AC application of 2G

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superconductors in rotating and linear motors. We are convinced that superconductors, suitable to produce the rotating field of rotating motors and the travelling field in case of linear motors will play an important role in future applications.
In order to find optimal solutions we need reliable computer simulations, based on e.g. experimental results on sample coils, for reduction of the AC-losses in the superconducting windings. Furthermore we need efficient and reliable cooling methods. Our final target is reliable superconducting drives with high efficiency, high power density, (high power and torque per volume and weight), high dynamics and also efficient closed cooling circuits to guarantee a safe operation.
HTS motors, with corresponding high efficiency and small size and weight, will save energy not only in terms of the efficiency but also in many other aspects like productivity, saving of space, faster acceleration of vehicles, etc. At Oswald several superconducting rotating and linear motors for various applications are under construction. One of them is the HTS motor SUTOR, to be described in this paper. Compared with a normal-conducting torque motor (e.g. with copper windings) it will be smaller by a factor of 2.5 to 3.
The Hochschule Aschaffenburg has profound knowledge in the measurement and layout of multiphase voltage systems that are generated by pulse width modulation. This expertise is used during the layout to get information about the behavior of sample coils working with amplified currents and external, rotating magnetic fields. The results of these measurements is used to improve the calculations to get a better tool to forecast the losses of the final motor. Additionally the Hochschule Aschaffenburg designs and builds a new inverter, that is specially designed to run motors with superconducting windings. The purpose of this new development is the optimized control and best possible protection of the prototype and to be able to use all the benefits a motor with superconductors offers.

2. Specifications of the SUTOR-motor

The motor type is a synchronous motor with permanent magnets on the rotor. The operating and size data are as follows:

Output power	155 kW
Torque	26 kNm
Speed	57 rpm
Field-weakening range	60 to 100 rpm
Number of poles	44
Mass	750 kg
Power factor	0.76
Electrical efficiency apart from cooling	99.5 %
Efficiency including cooling	93-95%

The superconducting stator windings are at low temperature (65-77 K), the rotor is at room temperature. The schematic layout of the motor is shown in figure 1, the superconducting coils are red. These generate out of a three phase alternating current a rotating magnetic field to which the rare earth permanent magnets are connected.

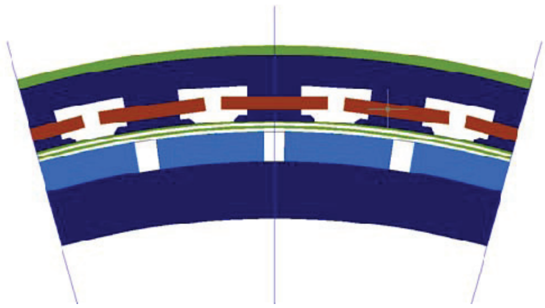

Fig. 1.schematic layout of Stator and Rotor

The superconducting coils are made of 2G YBCOcc with a tape width of 6mm. Each tape will carry approx. 100Arms, a length of 1.6km is needed for one motor. The coils will be driven with a voltage of 400V and the external field during operation will be in the range of up to 0,3T.
To be able to estimate the losses with the formulations found in the tests of the sample coils, the distribution of the electric and magnetic fields are calculated with FEM. With these values, the losses in the iron laminations, the losses in the superconductors due to transport current and external magnetic fields and the eddy current losses in the substrate and the stabilizing layers are calculated.

Since the motor operates at different speeds, loads, and short-time overloads the amount of AC-loss strongly depend on the corresponding specific operation duty in terms of current, frequency and magnetic fields.
All the losses, mentioned above, are calculated separately even though, in fact, they are interdependent. The calculated loss rates, for various operation powers and speeds, are shown in the following diagrams. All losses are given as relative values, 100% corresponds to the overall expected AC losses in the superconductors at the rated motor values. This value is very dependent on the Ic value the used superconductors will have and can therefore vary from 500W up to 800W.

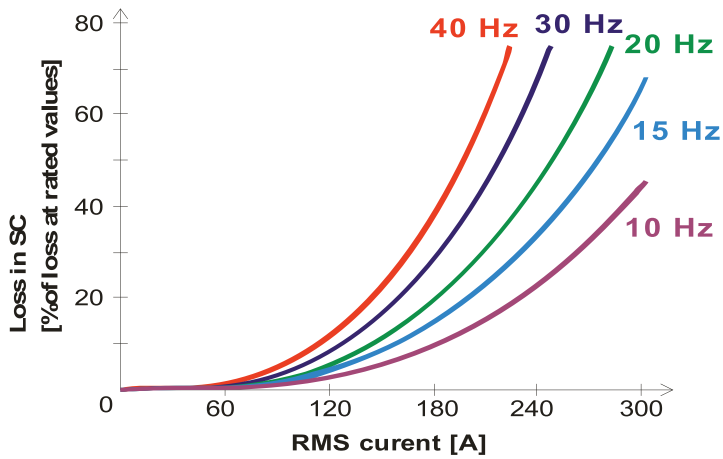

Fig. 2. Transport current losses in the coils, caused by the AC current. Values are calculated according to [1]

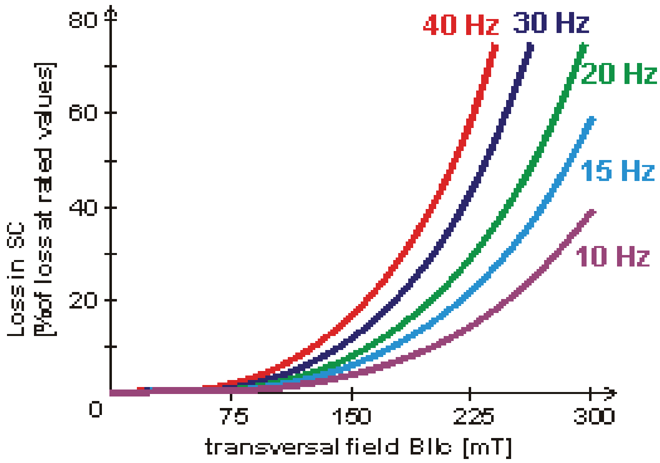

Fig. 3. Losses in the coils, caused by the external magnetic fields of the permanent magnets and the other phases. Values are calculated according to[2]

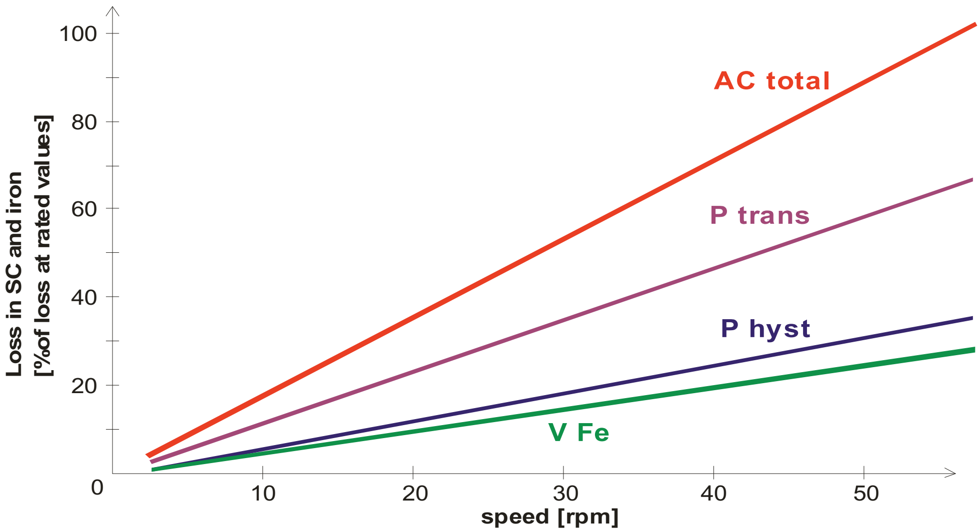

Fig. 4. Losses in the motor in the normal speed range. The AC losses of the superconductors consist of the transport current losses and the hysteresis losses. The iron losses are also shown, but are not included in the total losses.

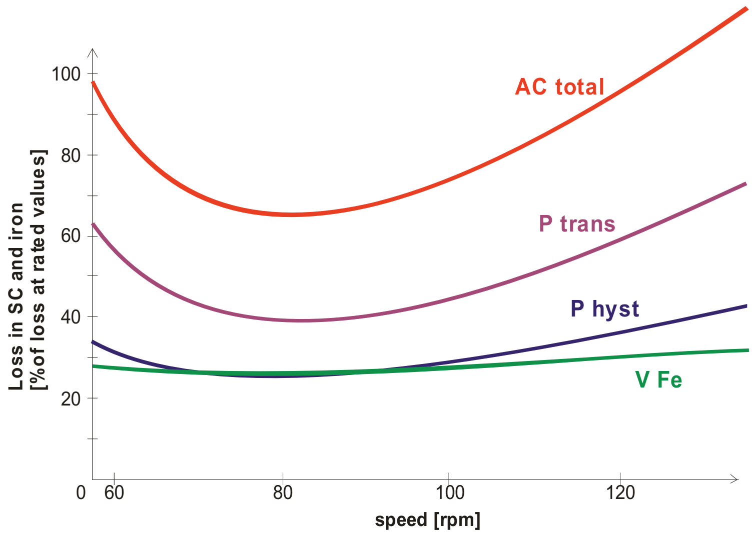

Fig. 5. Losses in the motor in the field weakening speed range. The AC losses of the superconductors consist of the transport current losses and the hysteresis losses. The iron losses are also shown, but are not included in the total losses.

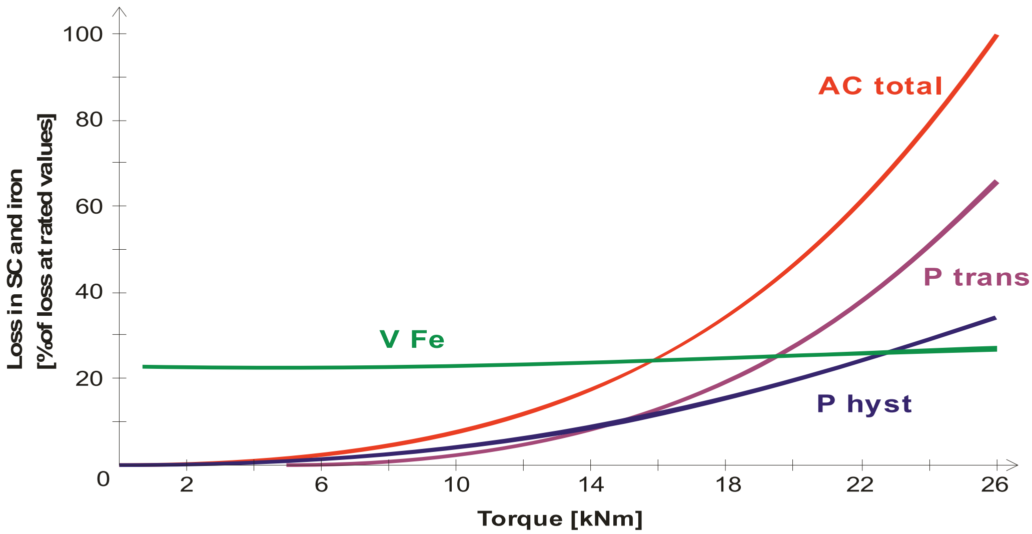

Fig. 6. Losses in the motor at the rated speed for partial load. The AC losses of the superconductors consist of the transport current losses and the hysteresis losses. The iron losses are also shown, but are not included in the total losses.

3. Conlusion

Our SUTOR motor is a first step to introduce HTS windings for high-torque motor applications. The present design is based on preliminary investigations and computer simulations. We are going to build this motor and start a testing program in 2012. In the meantime we expect new HT superconducting tapes with better performance to further reduce the AC losses. These are needed to reduce the cooling demands and therefore result in a high over-all efficiency.

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